IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Larry C. Olsen et al.

Application No. 10/581,281

Filed: May 31, 2006

Confirmation No. 3124

For: THERMOELECTRIC DEVICES AND APPLICATIONS FOR THE SAME

Examiner: Shannon M. Gardner

Art Unit: 1795

Attorney Reference No. 23-65037-09

FILED VIA EFS

ON August 31, 2009

FILED VIA ELECTRONIC FILING SYSTEM
COMMISSIONER FOR PATENTS

DECLARATION UNDER 37 C.F.R. § 1.131

We, Larry C. Olsen, John G. DeSteese, Peter M. Martin, John W. Johnston and Timothy J. Peters, declare as follows:

1. We are joint inventors of the above-identified application.

2. We have reviewed the Office action dated April 30, 2009. It is our understanding that certain claims are rejected in the Office action dated April 30, 2009, as allegedly being anticipated under 35 U.S.C. § 102(e) by U.S. Pat. Pub. No. 2004/0231714 A1 ("Stark"), which has an alleged priority date of May 19, 2003. It is also our understanding that certain claims are rejected as allegedly being anticipated under 35 U.S.C. § 102(e) by U.S. Pat. Pub. No. 2004/0094192 ("Luo"), which has an alleged priority date of March 24, 2003.

3. EVIDENCE OF REDUCTION TO PRACTICE AND OPERABILITY
   - Exhibit A hereto is a true copy of an Invention Report document signed prior to March 24, 2003, disclosing and illustrating reduction to practice inventions recited in certain of the pending claims.
   - Exhibits B-1 and B-2 are computer screen shots showing photographs taken by Timothy Peters (and photographs alone) of equipment we had built and used to test and evaluate, prior to March 24, 2003, the embodiment of the power source of the invention that is shown in the photographs and as recited in certain of the pending claims.

- Exhibit C is a computer screen shot showing a photograph taken prior to March 24, 2003 of an embodiment of the power source of the invention and as recited in certain of the pending claims, the power source embodiment being a flexible substrate with bismuth-telluride thermocouples and metal bridges between thermoelements, which embodiment we had built and tested prior to March 24, 2003.
- Exhibit D is a true copy of an Invention Report document signed prior to March 24, 2003, disclosing and illustrating conception of the invention as recited in certain of the pending claims.
- Exhibit E is a true copy of a PowerPoint document evidencing the reduction to practice and operability for its intended purpose, prior to March 24, 2003, of an embodiment as recited in certain claims of this application, of an ambient thermal energy thermoelectric power source prototype (utilizing a commercially available thermoelectric module). Exhibit E including, e.g., page 1 being a graphical image of an embodiment of the ambient thermal energy thermoelectric power source prototype, page 2 showing an embodiment of circuitry of the thermoelectric power source prototype using a commercially obtained theremoelectric module (TE module) including a voltage amplifier with which the TE module operated, prior to March 24, 2003, to power an RF Tag, page 3 being a graph of the output of the TE power source prototype using ambient solar energy, prior to March 24, 2003, page 4 illustrating the contrast between a conventional discrete element TE module and a graphical illustration of an embodiment of the thin film TE module prototype (see Exhibit F for this prototype thin film TE module) used, prior to March 24, 2003, and page 5 being a photograph taken prior to March 24, 2003, showing a mock-up of the TE power source prototype using ambient thermal energy with the thin film TE module (see Exhibit F).
- Exhibit F is a true copy of a PowerPoint document evidencing reduction to practice and operability for its intended purpose, prior to March 24, 2003, of an embodiment as recited in certain claims of this application, of a thin film, thermoelectric power source device. Exhibit F includes, e.g., pages 1-4 with illustrations and photographs of bismuth telluride thin films used, prior to March 24, 2003, in prototypes of embodiments of the TE power source and of TE modules with such thin films, as recited in certain claims of the application, and page 5 showing thermographic imagery of a prototype thin film TE power source in operation, prior to March 24, 2003, with a temperature difference of about 6ºC.
- Exhibit G are true copies of graphed data obtained from operation, prior to March 24, 2003, of a prototype of an embodiment of the TE power source having heat pipes, as recited in certain claims of the application, illustrating the operability of the TE power source for its intended purpose. For example, page 8 is a graph of the power responsive

to the temperature difference across a prototype thin film TE power source (with heat pipes) over the range 3ºC to 22ºC as measured prior to March 24, 2003.

- Exhibit H is a true copy of tabulated data obtained, prior to March 24, 2003, from operation of a prototype of an embodiment of the TE power source having heat pipes, as recited in certain claims of the application, illustrating the operability of the TE power source for its intended purpose.

The redacted portions of the Exhibits do not qualify or dispute any of the unredacted portions.

4. We conceived of and reduced to practice in the United States apparatus and methods for generating electrical energy from an environment having two different temperature regions wherein we conceived and reduced to practice a thermoelectric power source (TE device) having a first side in communication with means for transmitting ambient thermal energy collected in a first temperature region using metallic wire thermocouples or thin film semiconductors assembled in alternating p- and n-type arrays, as recited in certain of the claims prior to March 24, 2003. See Exhibits A-H. For example, see Exhibit E, page 3 with a graph of the output of a commercially obtained TE module used in an embodiment of the TE power source as recited in certain of the claims for production of electrical energy using the TE module in the TE power source prototype using ambient solar energy, prior to March 24, 2003, and Exhibit F pages 1-3 illustrating an embodiment of the thin film theremocouples used in a TE power source prototype as recited in certain claims, prior to March 24, 2003, and page 4 being a photograph taken prior to March 24, 2003, showing a prototype of the ambient thermal energy thin film TE power source and Exhibit F at page 5 showing thermographic imagery of the operation, prior to March 24, 2003, of a prototype of the thin film TE power source at a temperature difference of about 6ºC.

5. We conceived of and reduced to practice in the United States of thermoelectric power source methods and apparatus as set forth in item 4, having a second means for transmitting ambient energy collected in the second region by conduction, as recited in certain of the claims prior to March 24, 2003. See Exhibits A-H, for example, see Exhibit E, page 3 with a graph of the output of a prototype of the TE power source operating on ambient solar energy, prior to March 24, 2003, as recited in certain of the claims, page 5 a photograph taken prior to March 24, 2003, showing a prototype of an ambient thermal energy TE power source and Exhibit F at page 5 showing thermographic imagery of the operation, prior to March 24, 2003, of a prototype thin film TE device operating with a temperature difference of about 6ºC, and the Exhibit H tabulation of data obtained from operation, prior to March 24, 2003, of a TE device having two heat pipes on a hot and a cold side, respectively. Heat is conducted to and from TE elements through the hot and cold shoes, respectively, the heat pipes, thereby transferring heat by convection, evaporation and condensation inside the heat pipes.

6. We conceived of and reduced to practice in the United States the use of apparatus and methods as set forth in item 4 above having first and second temperature regions with differences of less than, equal to, or greater than 15°C, as recited in certain of the claims prior to March 24, 2003. See Exhibits A-H, for example, see Exhibit F at page 5 showing thermographic imagery of the operation, prior to March 24, 2003, of a prototype of the thin film TE device operating with a temperature difference of about 6ºC.

7. We conceived of and reduced to practice in the United States a power source comprising the methods and apparatus as set forth in item 4 above, including a super capacitor and/or at least one voltage amplifier, as recited in certain claims, prior to March 24, 2003. See Exhibits A – H. For example, Exhibit E, page 2 evidences the reduction to practice and operability for its intended purpose, prior to March 24, 2003 of a TE power source prototype capable of producing useful power by heating a hot shoe of the TE power source with solar energy while the cold side of the TE power source was transferring heat into the ground. The TE power source included a voltage amplifier to supply an energy storage means (super capacitor) to power an RF Tag that transmitted temperature data wirelessly to a nearby building.

8. All statements made herein and of our own knowledge are true and all statements made on information are believed to be true; and further, these statements were made with the knowledge that willful false statements and like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that any such willful false statements made may jeopardize the validity of the application or any patent issuing thereon.

Date August 31, 2009 — Larry C. Olsen
Larry C. Olsen

Date August 31, 2009 — John G. DeSteese
John G. DeSteese

Date ____________ — ____________
Peter M. Martin

Date ____________________ ____________________
John W. Johnston

Date ____________________ ____________________
Timothy J. Peters

Battelle
. . . Putting Technology To Work

B&R CODE:

INVENTION REPORT

IR No. 13664 - B

Date Received

Source Lab
☐ PNNL
☐ BCO

General Procedure
(1) Each page of the description, including any drawing(s) or photograph(s), must be signed and dated by each inventor and two witnesses who have read and understand the invention and the entries on this Invention Report.
(2) Send the original and two copies to the Intellectual Property Services (IPS) (PNNL) or the Intellectual Property Law Department (IPLD) (BCO).
(3) If you have questions, please call the appropriate IP office.

TITLE

Sputter Deposition of Bi_2Te_3 and Related Alloys for Thermoelectric Applications

Inventor Name(s)	Home Address	Payroll No	Citizenship	Org Code	Line Manager
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
4					
5					

Witness 1 Name: [redacted] **Witness 2 Name:** [redacted]

PNNL FUNDING SOURCE FOR CONCEPTION OR DEMONSTRATION

1830
☐ DOE
☐ Other Govt. Agency Related Services
☐ LDRD
☐ Work for Others
☐ CRADA #

1831 OR BATTELLE PRIVATE
☐ 1831 Contract # ____
☐ Industrial
☐ Federal Govt.
☐ State & Local Govt.
Battelle Funds:
X☐ PNNL IR&D
☐ BMI Core Tech or Tech Platform
☐ BMI Commercial Mkt Sector
☐ BMI IR&D
☐ BCO-Gov't Mkt Sector
No funds:
☐ Personal Time

1831 or Battelle Private Cont.
Was 1830 data necessary for conception or test?
☐ Yes ☐ No
If yes, was the 1830 data available to the public?
☐ YES ☐ NO
If yes, reference/publication #____

Provide Work Package No.(s) used for conception: [redacted]
Provide Work Package No.(s) used for reduction to practice: [redacted]
Funding Market Sector: ____ Funding Tech Platform ____

BCO FUNDING SOURCE FOR CONCEPTION OR DEMONSTRATION

☐ Industrial ☐ Govt. ☐ IR&D
☐ Battelle
☐ Private (on own time)

Client Name: ____ Agency: ____
If DOE, 1830 related? ☐ Yes ☐ No
Contract No.: ____ Contract No.: ____

[redacted]

Provide Work Package No.(s) used for conception: ____
Provide Work Package No.(s) used for reduction to practice: ____

INVENTOR SIGNATURES

1 Signature	Date	2 Signature	Date
[illegible]	[redacted]	[illegible]	[redacted]
3 Signature	**Date**	**4 Signature**	**Date**
[illegible]	[redacted]		

WITNESS SIGNATURES

Witness 1 Signature	Date	Witness 2 Signature	Date
[illegible]	[redacted]	[illegible]	[redacted]

EXHIBIT A

ORIGIN

Date of Conception
[redacted]
Date of 1st Record
[redacted]
First disclosed to:
John DeSteese
Identify 1st Record
☐ This form
☐ Lab Record Book # _____
X☐ Other (identify the document, page Nos. and location) Lab Data Book, Rm 120, [redacted]

Test/Proof-of-Principle/Reduction to Practice
X☐ Yes ☐ No
Date of Tes[redacted]

If yes, describe in attached test record

☐ Drawings ☐ Report
☐ Other attachments

..closed outside of Battelle
☐ Yes X☐ No

If yes, to whom?

Disclosure was
☐ Oral ☐ Written ☐ Proprietary

PUBLISH/USE

[redacted] been published?
[redacted]

Do you plan to publish/present the invention?
[redacted]

If Yes, [redacted] a copy of the publication when you send this completed form in.
[redacted]

Do you plan to disclose/demonstrate the invention or have you disclosed/ demonstrated the invention to non-Battelle, non-government personnel?
[redacted]

If yes, is there now, or do you plan to have a Non-Disclosure Agreement in place covering the disclosure to such personnel?
[redacted]

Has the invention been used or planned to be put into use?
[redacted]

Enter text or graphics in the shaded areas below and double click Help for assistance.

ABSTRACT

Help This invention describes a process for sputter deposition of thin films of alloys of Bi_2Te_3, Sb_2Te_3 and Bi_2Se_3 for thermoelectric energy conversion. The approach allows deposition of these films on glass and flexible substrates such as Kapton. The process was used to deposit n-type and p-type films that exhibit properties nearly as good as measured for bulk materials. [redacted]

RELEVANT KEYWORDS (Optional)

Help Thermoelectric films, thin films, power sources

INVENTOR SIGNATURES

1 Signature	Date	2 Signature	Date
Larry C. Olsen	[redacted]	Pat M Mart	[redacted]
3 Signature John W. Johnston	Date [redacted]	4 Signature	Date

WITNESS SIGNATURES

Witness 1 Signature	Date	Witness 2 Signature	Date
Charles W. Stewart	[redacted]	Ronald C. Teeter	[redacted]

EXHIBIT A

DETAILED DESCRIPTION OF THE INVENTION

[redacted]

The best thermoelectric materials for power generation in the 0°C to 100°C temperature range are semiconductors and related alloys based on the bismuth-antimony-telluride-selenium (Bi-Sb-Te-Se) materials system. This disclosure concerns procedures that have been developed which allow the sputter deposition of thin films of these materials that can be utilized to fabricate high voltage, low power thermoelectric (TE) power sources. Films were deposited by RF magnetron sputtering simultaneously from two of three possible sources, namely, targets made of Bi_2Te_3, Sb_2Te_3 and Bi_2Se_3. RF power supplied to each of the targets, substrate temperature and sputtering gas pressure were varied to determine deposition conditions that resulted in films with appropriate properties. Figure 3 describes the variation of material parameters with sputtering conditions. N-type TE material is obtained by supplying RF power of 30 watts to a Sb2Te3 target and 20 watts the the Bi2Te3 target, and with the substrate at the ambient temperature, whereas p-type material was achieved with power levels of 30 watts and 10 watts to the Sb_2Te_3 and Bi_2Te_3 targets, respectively. A sputtering gas pressure of 3 millitorr was utilized in both cases. A picture of a miniature thin film TE couple fabricated with the disclosed processe is shown in Figure 4. [redacted] The disclosed process will allow the deposition of hundreds of TE couples on flexible material such as Kapton [redacted]

[redacted]

[redacted]

Help

INVENTOR SIGNATURES

1 Signature	Date [redacted]	2 Signature	Date [redacted]
3 Signature	Date [redacted]	4 Signature	Date

WITNESS SIGNATURES

Witness 1 Signature	Date [redacted]	Witness 2 Signature	Date [redacted]

EXHIBIT A

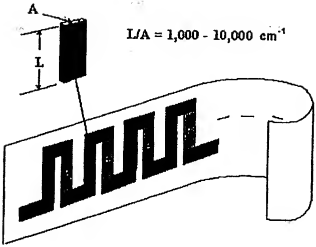

Figure 2. Concept of a TE Module Based on Thin Films on a Flexible Substrate.

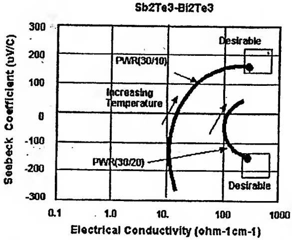

Figure 3. Variation of Seebeck coefficient with electrical conductivity for a range of sputtering parameters.

INVENTOR SIGNATURES

1 Signature	Date [redacted]	2 Signature	Date [redacted]
3 Signature	Date [redacted]	4 Signature	Date

WITNESS SIGNATURES

Witness 1 Signature	Date [redacted]	Witness 2 Signature	Date [redacted]

EXHIBIT A

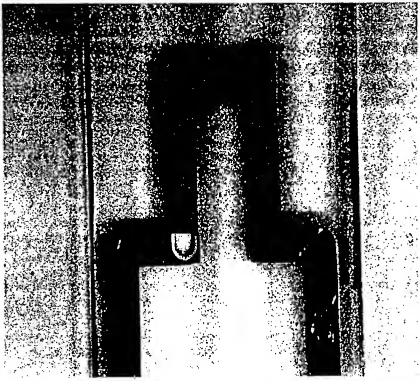

Figure 4. Picture of thin TE couple deposited with the disclosed process.

INVENTOR SIGNATURES

1 Signature	Date [redacted]	2 Signature	Date [redacted]
3 Signature	Date [redacted]	4 Signature	Date

WITNESS SIGNATURES

Witness 1 Signature	Date [redacted]	Witness 2 Signature	Date [redacted]

EXHIBIT A

POSSIBLE APPLICATIONS (Optional)

Help

[redacted]

PRIOR ART (Optional)

Help

PRODUCT DIFFERENTIATION (Optional)

Help

STATUS OF THE INVENTION (Optional)

Help

ADDITIONAL CONSIDERATIONS (Optional)

Help

(PNNL Only) LINE MANAGER OR AUTHORIZED DERIVATIVE CLASSIFIER (ADC) SIGNATURE

1. To the best of my knowledge and belief, the attached description ☐ DOES ☑ DOES NOT contain information classified as RESTRICTED DATA, related to national security or to uranium enrichment, or related to storage and disposal of high level nuclear waste or spent fuel, or other sensitive or restricted data (e.g., UCNI, export control).
2. If the technology described in the attached description was generated in a classified or potentially classified subject area, an Authorized Derivative Classifier should review it.

☑ Line Manager Signature *Pete M Mart* Date [redacted]

☐ ADC

INVENTOR SIGNATURES

1 Signature *Larry C Olson*	Date [redacted]	2 Signature *Pete M Mart*	Date [redacted]
3 Signature *John W Johnston*	Date [redacted]	4 Signature	Date

WITNESS SIGNATURES

Witness 1 Signature *Walter D Bennett*	Date [redacted]	Witness 2 Signature *Donald R Stewart*	Date [redacted]

EXHIBIT A

From: DeSteese, John G [mailto:john.desteese@pnl.gov]
Sent: Monday, April 14, 2008 3:17 PM
To: [redacted]
Cc: Matheson, James D; Olsen, Larry C; Silva, Robert R
Subject: FW: Pictures of Test Set-Up

[redacted]

I am forwarding Tim Peter's e-mail showing reduction to practice to show the date stamp on the original.

John D.

From: [redacted]
Sent: [redacted]
To: DeSteese, John G
Subject: Pictures of Test Set-Up

Attached

teflmst1.jpg teflmst2.jpg

<<teflmst1.jpg>> <<teflmst2.jpg>>

EXHIBIT B

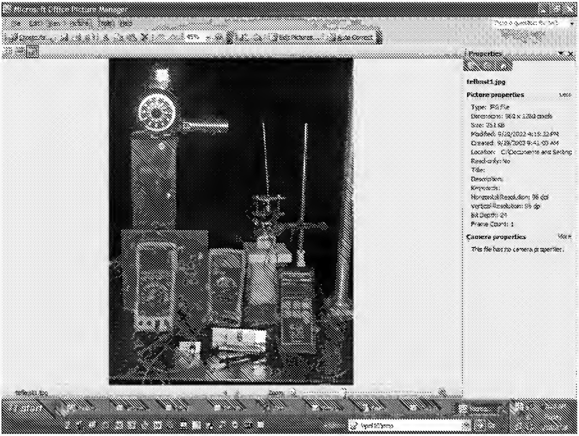
Microsoft Office Picture Manager
Properties
Picture properties
Camera properties
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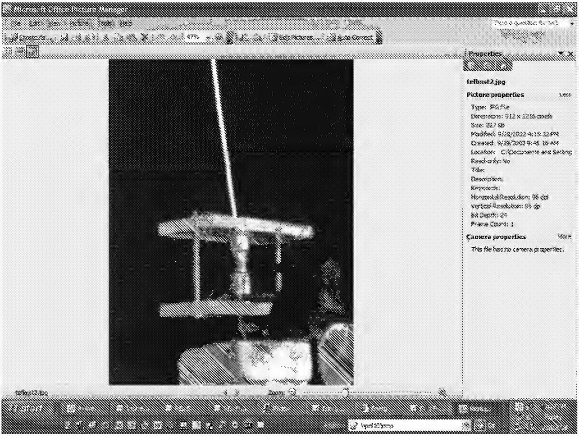
EXHIBIT B-1

EXHIBIT B1


Microsoft Office Picture Manager
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tefbust2.jpg
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Modified: 9/20/2002 4:15:32 PM
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Keywords:
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Bit Depth: 24
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EXHIBIT B-2

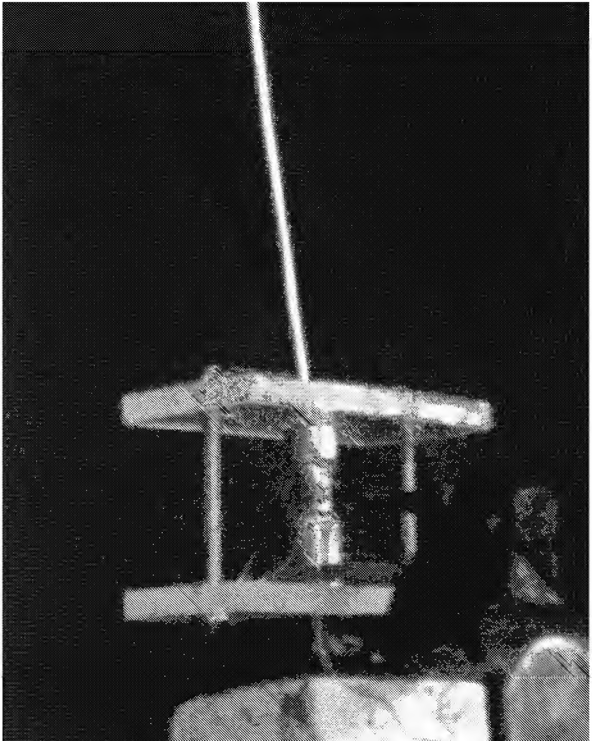


EXHIBIT B-2

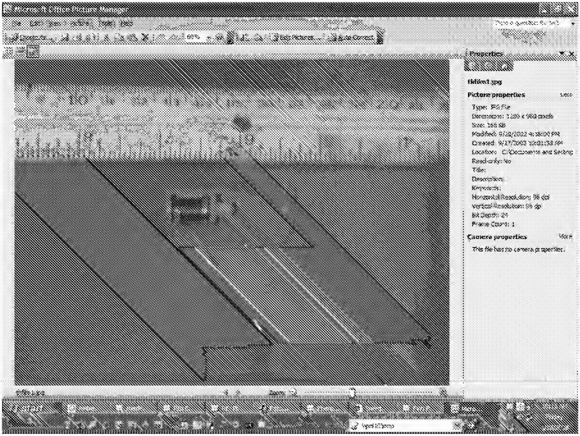

Microsoft Office Picture Manager
Properties
Picture properties
Camera properties
This file has no camera properties.

EXHIBIT C

Battelle
. . . Putting Technology To Work

INVENTION REPORT(a)

IPS File No. E-1861

Title: Thermoelectric Device for Ambient Energy Harvesting
23-69853-01

ORIGINATOR(S)

	Name	Phone	Citizenship	Payroll No.	Org. Code	Center Acronym	Line Manager Name (See Sensitivity Block) (d)
1.(b)	J.G. DeSteese	5-2057	US	34865	D948		Mark P. Morgan
2.(b,c)							
3.(b,c)							
4.(b,c)							
5.(b,c)							

WIT

Name of Witness 1 (b) Jesse A. Willett II — Name of Witness 2 (c) Kevin L. Gervais

ORIGIN

Date of Conception 5/21/99 — Date of first Record 5/21/99

Identify First Record:
__This Transmittal
__Lab record book number________
X Other – Identify in attached description: Unnumbered Journal

TEST OF PROOF-OF-PRINCIPLE Yes _____ No X — Date of Test ________

If yes, describe in attached test record

__ Drawing(s) __Report __Other attachment

Name of non-inventor to whom technology was first disclosed (can be same as witness): John F. Hauer

Disclosure was X oral __written __confidential

FUNDING

SOURCE OF FUNDING FOR CONCEPTION, DOCUMENTATION FOR DEMONSTRATION

1830 TMC Pool # 95428 — 1831 or Battelle Private — 1831 or Battelle Private (contd)

X DOE __Other Gov't Agency Related Services __1831 Contract # ________ __Industrial __Gov't
__LDRD __Commercial Work for Others __IR&D
__CRADA #_____ __Private (non-1830, non-1831)

Was 1830 date necessary for conception or test? Yes ____ No____.
If yes, was the 1830 data available to the public? Yes ___ No ___.
If yes, reference #__________________

PROVIDE WORK PACKAGE NO.(s), USED FOR CONCEPTION OR TEST. K83838 (If non, explain in a separate memo.)

PUBLISH / USE

Do you plan to publish/present? Yes X No ______
If yes, date Unknown

PNL/BN # __________ (If cleared)
Journal or Conference (abbreviate) ____________________

Do you plan to demonstrate the invention to non-Battelle, non-project personnel? Yes X No ______
If yes, date 8/26/99

Will you have a non-disclosure agreement for non-government observers? Yes X No________

Has the invention been used or planned to put into use? Yes ______ No X
If yes, date ______________

Used by __Battelle __Other Entity
Used on __Battelle premises/land __Off-site

SENSITIVITY

LINE MANAGER OR AUTHORIZED DERIVATIVE CLASSIFIER (ADC) SIGNATURE (d)

1. To the best of my knowledge and belief, the attached description ☐ DOES ☑ DOES NOT contain information classified as RESTRICTED DATA, related to national security or to uranium enrichment, or related to storage and disposal of high level nuclear waste or spent fuel, or other sensitive or restricted data (e.g., UCNI, export control).

2. If the technology described in the attached description was generated in a classified or potentially classified subject area, the attached description should be reviewed by an Authorized Derivative Classifier.

☒ Line Manager
☐ ADC Signature [signature] Date 10/6/99

(a) Two-sided form
(b) Fill out reverse side of this form.
(c) If multiple inventors are named, specify in the attached description the contribution of each inventor.
If more than 5 inventors, continue on a separate form.
If an inventor is not a permanent Battelle employee, include temporary and permanent home address and phone number on attached description.
(d) If multiple Line Managers, only one need sign the sensitivity block, or ADC.

Received IPS
RECEIVED
OCT 08 1999
IP SERVICES

EXHIBIT D

(A) Duty of Disclosure Statement (for inventions)

For inventions that may lead to patents, it is a legal requirement that, throughout evaluation and patenting phases, the inventor(s) disclose(s) MATERIAL references (provide copies) that inventor(s) is/are aware of to IP Services.

Examples of MATERIAL information include:

A. Patents and publications which describe one or more features of the inventions or which would appear similar to the invention. Patents and publications can be our own or others. Publications include reports, conference presentations/proceedings, journal articles, newsletters (Greenie), newspaper articles, brochures and flyers;

B. Information evidencing that the invention, or a closely related invention, was in public use or "on sale" (not necessarily "sold") by anyone more than one year before the filling date of the U.S. application;

C. Information that the invention, or a closely related invention, was make in the United States by someone other than the inventor named in the patent application; and

D. Experimental results, either favorable or unfavorable, involving the invention, particularly any comparisons with the prior art.

Failure to comply fully with this duty may lead to unenforceability of any resulting patent.

You are NOT required to make a search or to certify that no prior art exists which is more pertinent than that cited. You are only required to answer to the best of your present knowledge.

It is requested that you list in the space provided below those items, if any, of information or date presently known to you that you believe may be MATERIAL to the invention claimed in the above-identified patent application; and that you read carefully the following acknowledgement.

(B) Acknowledgment

I (we) have read and understood the above description of the legally required duty of disclosure(we) hereby affirm that to the best of my (our) knowledge and belief, I (we) have complied with this duty by disclosing to Battelle IP Services as of the date of my (our) signature(s) on the front of this form the following items (identify all patents, publications, reports, data, or other documents):

PATENTS: None

(If none, write none. If necessary, attach additional sheet.)

PUBLICATIONS AND REPORTS: None

(If none, write none. If necessary, attach additional sheet.)

OTHER INFORMATION OR DATE:

(C) General Procedures

Attach a detailed description of the invention to this transmittal sheet; send the originals and 5 copies to Intellectual Property Services (IPS) Department. The detailed description should specifically define what the inventor(s) regard as the novel concept and, to the extent possible, how the invention is distinguished from known technology. It should include sketches or photographs that wold help to understand the concept, operative ranges of conditions or constituents, and advantages over similar known concepts. Each page of the description, including any drawing(s) or photograph(s) must be signed and dated by each inventor and two witnesses who have read and understand the invention. If you have questions, please call IP Services 375-2227.

Signatures of Inventors and Witnesses

I am an INVENTOR and have reviewed the information on the front side of this form, the attached description, and (A) complied with the duty of disclosure statement, (B) filled in the acknowledgment, and (C) followed the general procedures.

1. John G. DeSteese — date 10/5/99		2. — date
3. ~~Kevin L. Gervais 10-6-99~~ KLG 10-6-99 — date	4. — date	5. — date

I have read and understood the attached description.

Signature, Witness I — date	Signature, Witness 2 — date
[signature] 10/6/99	Kevin L. Gervais 10-6-99

EXHIBIT D

<u>Invention Report on Thermoelectric Device for Ambient Energy Harvesting</u>

October 5, 1999

John G. De Steese

A method for utilizing generally persistent temperature differences that exist naturally between adjacent environments (e.g., earth and the ambient atmosphere) is disclosed as a means of producing electric energy for sensors, monitors and other low-power end uses. This invention appears capable of supplying electric power of up to hundreds of milliwatts perpetually without an external fuel supply or human attention. When combined with rechargeable batteries and power conditioning electronics, this invention could supply a power demand profile that includes brief outputs of tens to hundreds of watts for communications and other higher power requirements.

The concept is illustrated in Figure 1. The core of the device is a series/parallel assembly of miniature thermocouples terminated at a cold and hot shoe at either end of the assembly. The concept can incorporate metallic wire thermocouples and all other thermoelectric materials. Miniature heat pipes are attached to each shoe to improve heat flow to or from the shoes. Power conditioning electronics and a battery may be incorporated and contained in a housing that preferably surrounds the thermocouple assembly.

In operation, one of the heat pipes is inserted into one of the thermal sources/sinks that drive the device. The other end remains in an ambient environment that provides a differential temperature across the thermocouple assembly. For example, the configuration represented in Figure 1exploits the nearly continuous difference in temperature between earth and ambient air. This difference persists diurnally and seasonally. In summer, the hot shoe would normally be in air and the cold shoe in the ground. In winter, the reverse would tend to occur. In either case, the differential temperature energizes the thermocouples to produce unconditioned electric power of up to hundreds of milliwatts. With appropriate electronic power conditioning, the thermocouples would charge the battery regardless of which end of the device is warmer.

The following example illustrates a representative design. Assuming an average temperature difference between shoes of 20°C and a Seebeck coefficient of 59 μV/°C (e.g., that of a Type E Chromel vs. Constantan thermocouple), an output of approximately 1 mW would be achieved with a series/parallel array of less than 1000 miniature wire thermocouples. It is envisioned that these will be assembled into a robust package using established micro-electromechanical systems (MEMS) technologies. The entire device would be less than 20cm long and 3cm diameter. The heat pipes constitute 70% of the overall estimated length and are amenable to being made shorter for use in some environments (e.g., between hot and cold environments in buildings). MEMS technologies are expected to make construction of larger assemblies (e.g., 100,000 miniature thermocouples) practical. A device with this many thermocouples would raise the unconditioned power of the concept to the hundreds of milliwatts level and higher.

In the potential applications envisioned for this concept, the intrinsically low energy conversion efficiency of thermoelectric elements is not a disadvantage. In comparison to the power demands of typical end uses (e.g., sensors, monitors, locators, etc.) the thermal energy sources of the environments that drive the device are infinitely large. Therefore, energy conversion efficiencies less that 5% are acceptable providing other design requirements (e.g., stored energy density, package size, thermal signature, etc.) are satisfied.

John G. DeSteese
Inventor

Oct. 5, 1999
Date

Jesse Whitt II
Witness 1

10/6/99
Date

Kevin L. Stewart
Witness 2

Oct 6, 1999
Date

EXHIBIT D

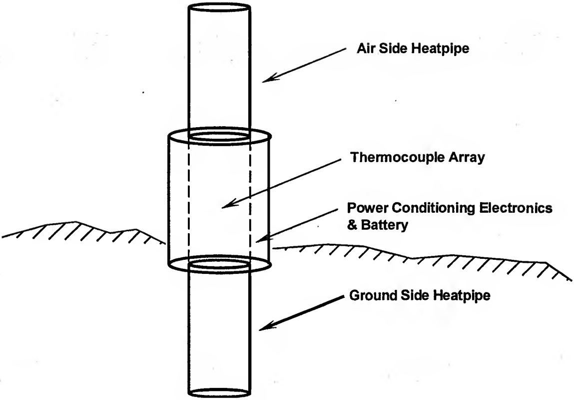


Figure 1: Representative Configuration of Thermoelectric Device for Ambient Energy Harvesting

John G. DeSteese
Inventor

Oct. 5, 1999
Date

Witness 1

Oct. 6, 1999
Date

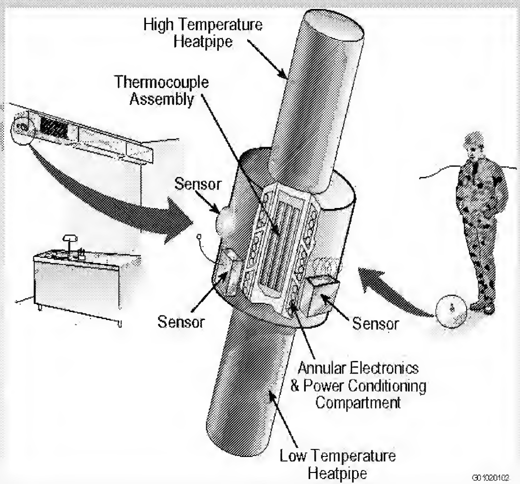
Kevin L. Gervais
Witness 2

Oct. 6, 1999
Date

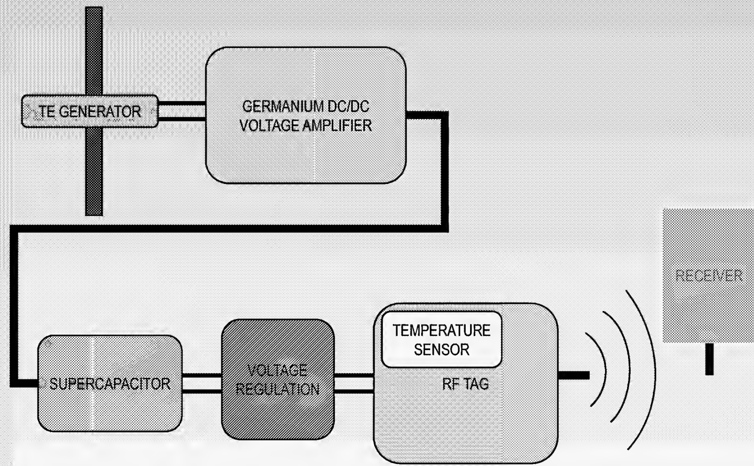
EXHIBIT D

Sensors Powered by Ambient Thermal Energy

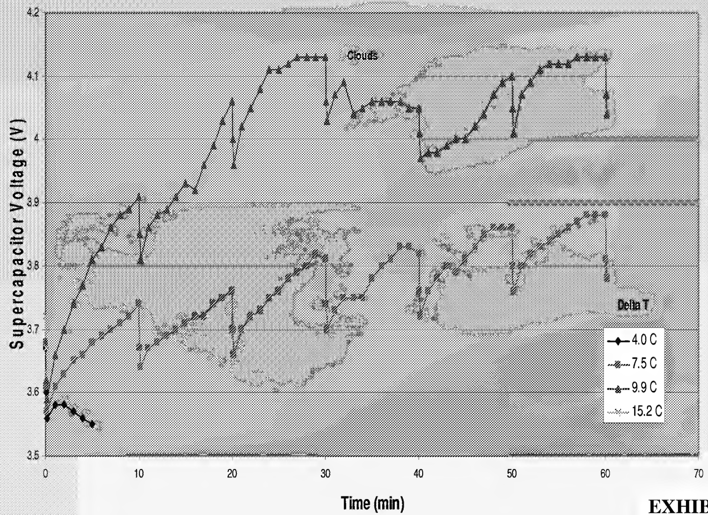
- Thermal energy scavenged from abundant ambient
- Device is rugged, light weight, suitable for field or facility use
- Perpetual power for life of application
- Independent, maintenance-free electric power for wireless sensing, surveillance, remote actuators and communications
- Potential for miniaturization



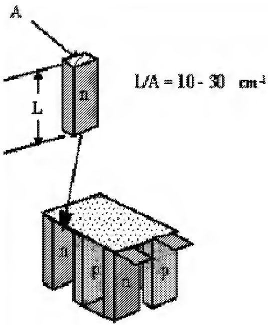
Concept Demonstration



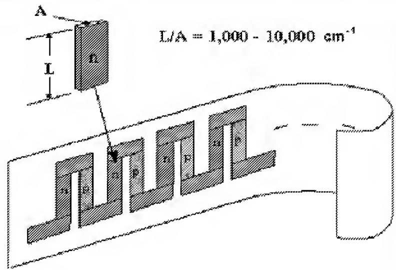
Charge Sustainability Demonstration with Solar Heating and Earth Sink



Concept Development



TE Module With Discreet Elements



Thin-Film TE Array

Size Comparison Between Thin-Film and Discrete Element TE Generators

[redacted]

Thin Film Semiconductors For TE Power Sources

Larry C. Olsen, John G. DeSteese and Peter M. Martin

- **Summary of Project**
  - Objective of program is to develop processes for sputter deposition of Bismuth Telluride (Bi-Te) thin films for fabrication of miniature, high voltage thermoelectric (TE) power sources.
  - Key results to date: (1) Bi-Te films with good properties deposited on glass and 2 mil Kapton; [redacted]
    (3) Demonstration TE battery with 24 thermoelements fabricated; [redacted]

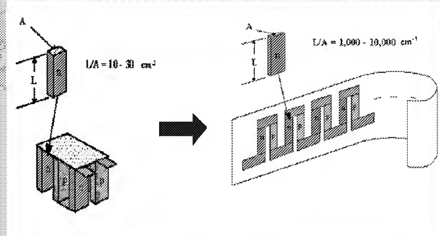
[redacted]

[redacted]

Thin Film Semiconductors For TE Power Sources

Larry C. Olsen, John G. DeSteese and Peter M. Martin

- **Technical Approach**
  1. Sputter Deposition Of N- And P-Type Bi-Te Alloys
  2. Fabrication of Miniature, High Voltage TE Batteries Based On Thin Film Thermocouples On Flexible Substrates (Kapton)



TE Module With Discreet Elements

Thin-Film TE Array

- **Milestones**

[redacted] Achieve Sputtered Bi-Te Films With Appropriate Properties
Demonstration TE Power Source Based On 2-mil Kapton
Prototype Ambient Powered Sensor With TE Battery

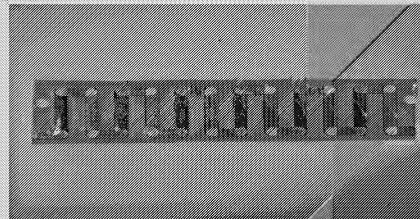
[redacted]

[redacted]

Thin Film Semiconductors For TE Power Sources

Larry C. Olsen, John G. DeSteese and Peter M. Martin

[redacted]



- Developed an Approach for Winding Flexible Thin Film Thermocouple Arrays
- Fabricated Demonstration Device to Develop Procedures for Connecting Tapes
- Characterized Demonstration Device and Used Results to Design 40 TW/1.0 Volt TE Battery

[redacted]

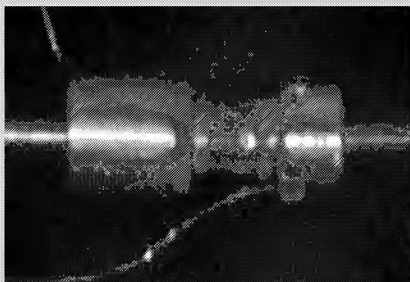
[redacted]

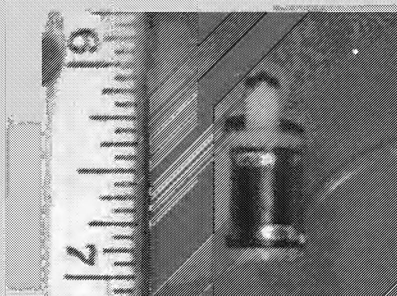
Thin Film Semiconductors For TE Power Sources

Larry C. Olsen, John G. DeSteese and Peter M. Martin

[redacted]

- **Demonstration Device Utilized Two Flexible TE Strings**





[redacted]

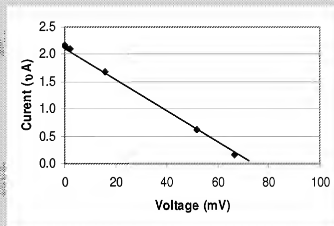
[redacted]

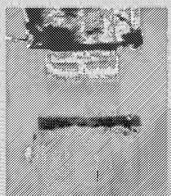
Thin Film Semiconductors For TE Power Sources

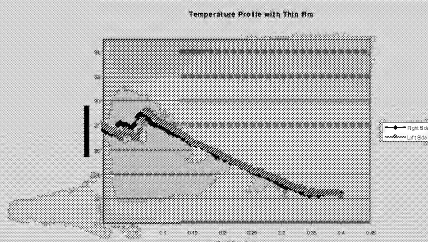
Larry C. Olsen, John G. DeSteese and Peter M. Martin

[redacted]

- Temperature Distribution Determined With IR Camera
- Measurement of Temperature Difference Across TE Elements Established Performance Was As Predicted







[redacted] EXHIBIT F – Page 5

Resistance Change vs. Time

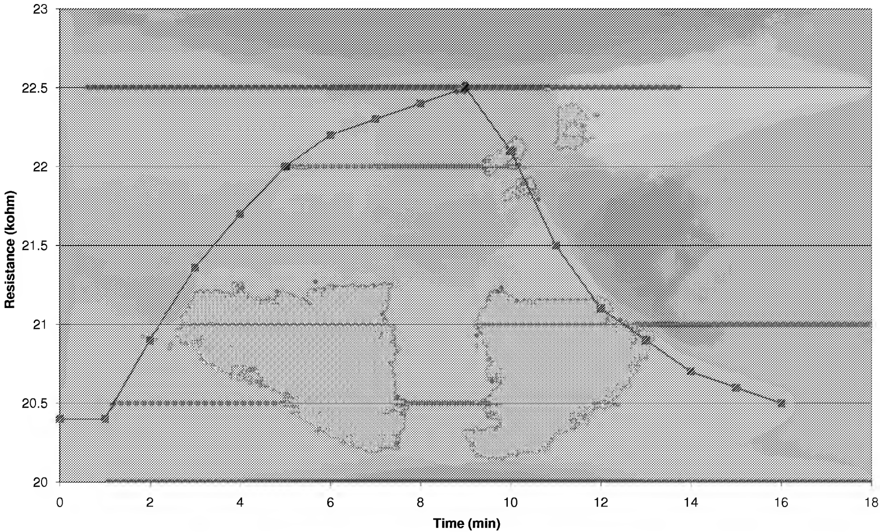
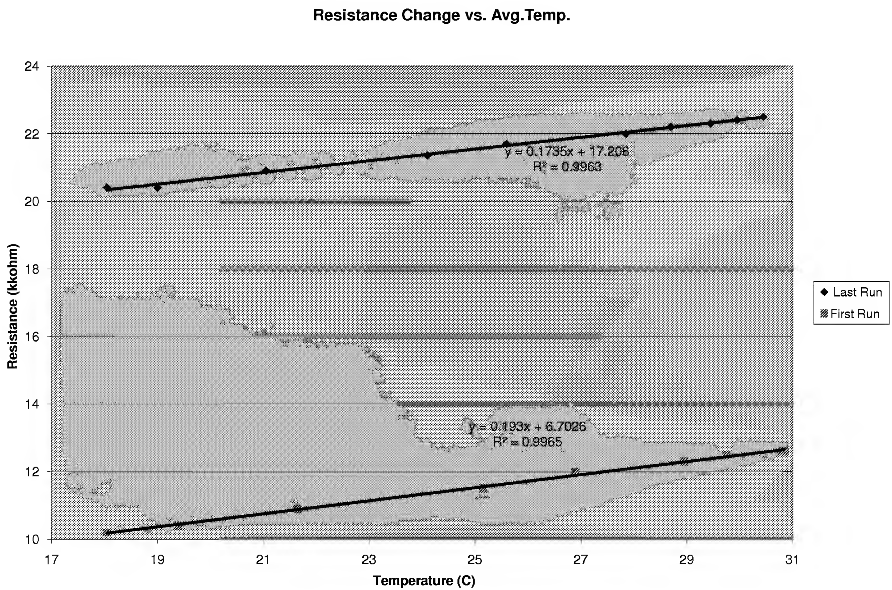


EXHIBIT G - Page 1


Resistance Change vs. Avg.Temp.
y = 0.1735x + 17.206
R² = 0.9963
y = 0.193x + 6.7026
R² = 0.9965
Resistance (kkohm)
Temperature (C)
24
22
20
18
16
14
12
10
17
19
21
23
25
27
29
31
Last Run
First Run

Voltage vs. Resistance

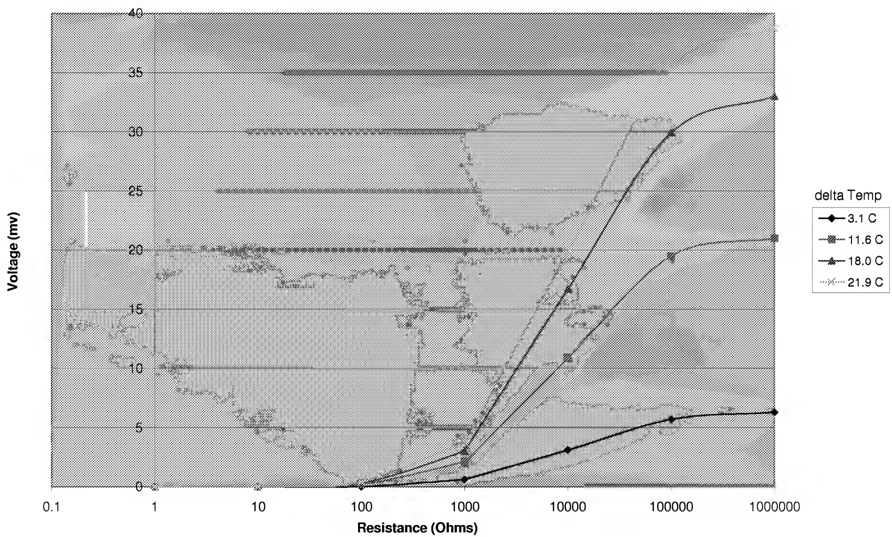


EXHIBIT G - Page 3

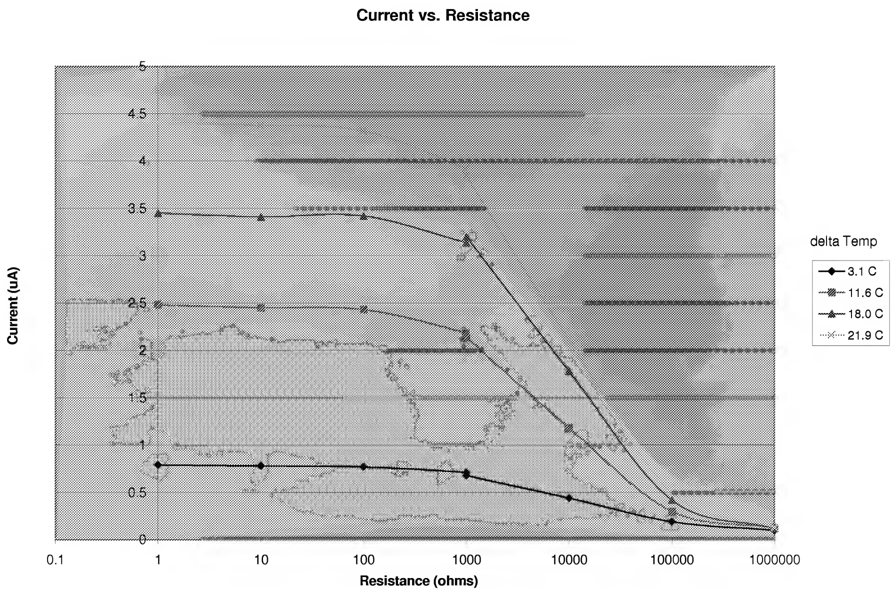
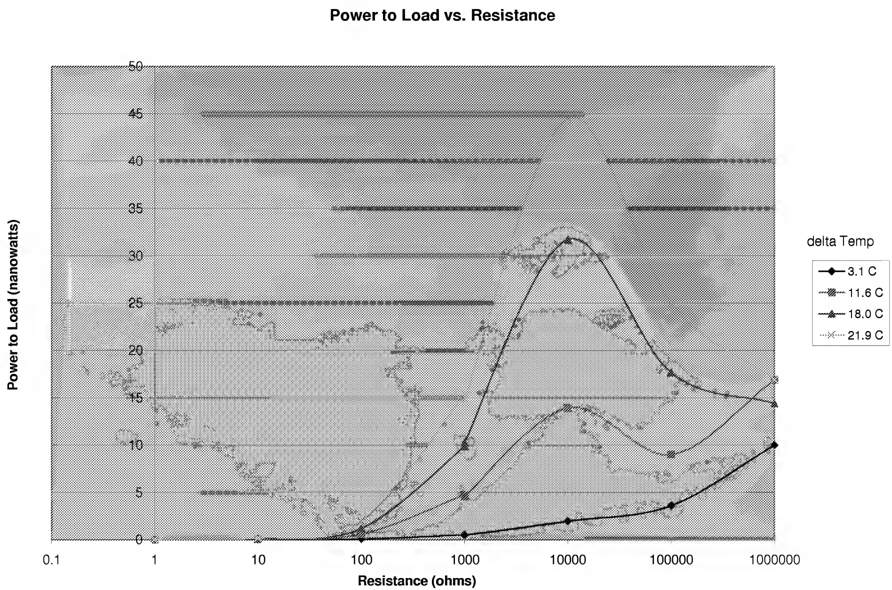


EXHIBIT G - Page 4


Power to Load vs. Resistance
Power to Load (nanowatts)
0
5
10
15
20
25
30
35
40
45
50
0.1
1
10
100
1000
10000
100000
1000000
Resistance (ohms)
delta Temp
3.1 C
11.6 C
18.0 C
21.9 C

Current vs. Voltage

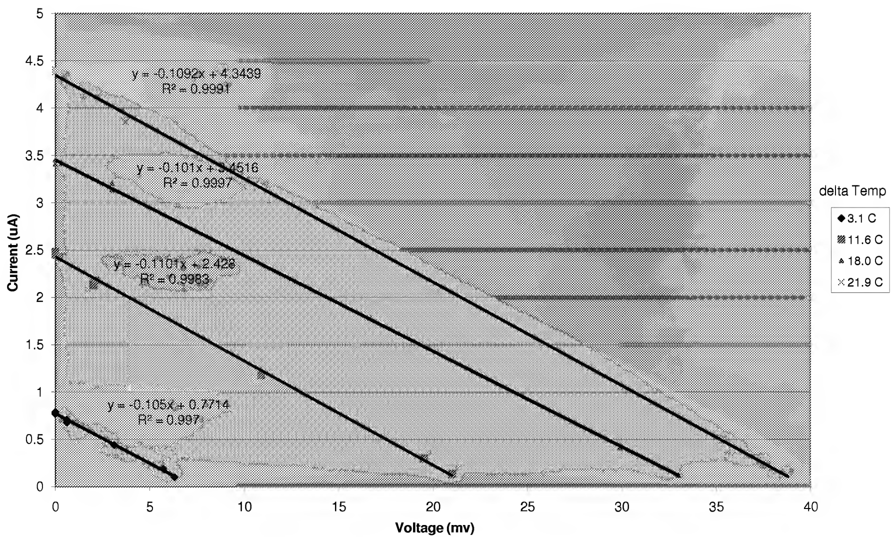
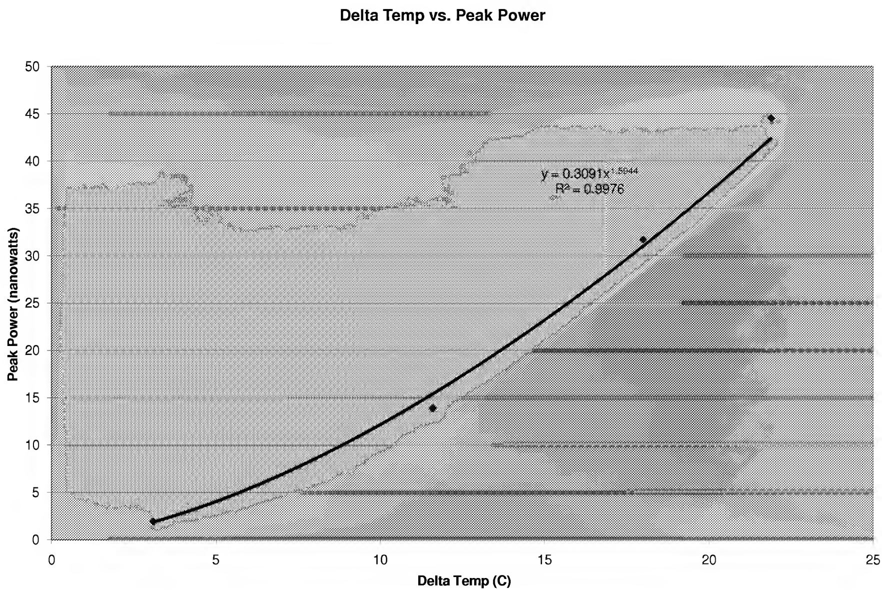
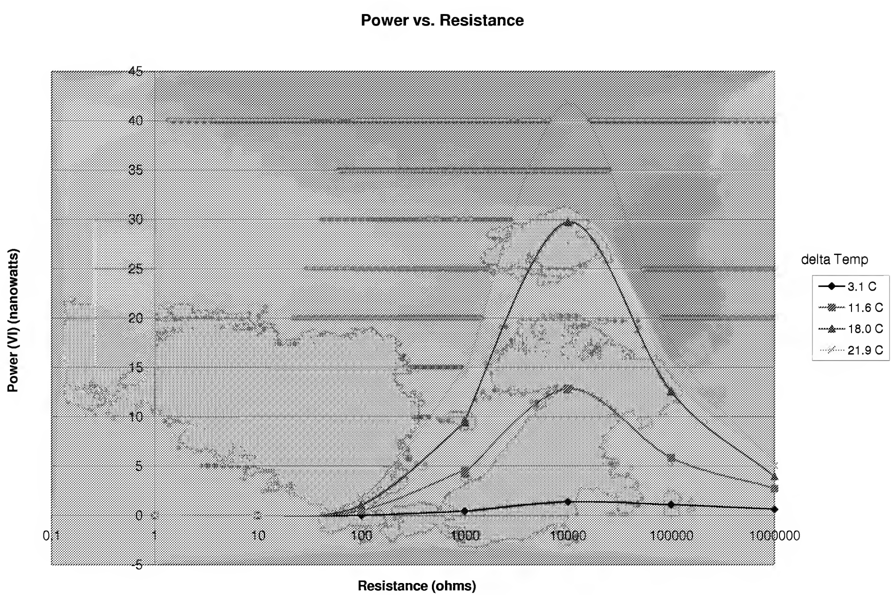


EXHIBIT G - Page 6


Delta Temp vs. Peak Power
y = 0.3091x^1.5944
R² = 0.9976
Peak Power (nanowatts)
Delta Temp (C)
0
5
10
15
20
25
30
35
40
45
50



Power vs. Resistance
Power (VI) (nanowatts)
45
40
35
30
25
20
15
10
5
0
-5
0.1
1
10
100
1000
10000
100000
1000000
Resistance (ohms)
delta Temp
3.1 C
11.6 C
18.0 C
21.9 C

10/22/2002

Thin Film Heatpipe - First Lab Bench Tests with gold stripes - 12 junctions

Run 1

Time (min)	Resistance (Kohm)	Top Temp (C)	Bot Temp (C)	Avg. Temp (C)
0	10.2	20.2	15.9	18.05
1	10.4	23.1	15.7	19.4
2	10.9	27.5	15.8	21.65
3	11.5	34.5	15.8	25.15
4	12	37.5	16.3	26.9
5	12.3	41.6	16.3	28.95
6	12.5	42.8	16.7	29.75
7	12.6	44.9	16.7	30.8
8	12.6	44.5	17.2	30.85

delta Temp = 29.7 C (uncorrected)= 18.0 C (corrected)
Top Temp = 46.9 C, Bot Temp = 17.2 C

Resistance (ohms)	Voltage (mv)	Current (uA)	Power to Load (I^2*R)(nanowatts)	Power (VI) (nanowatts)
1	0	3.45	0.0119025	0
10	0	3.41	0.116281	0
100	0.3	3.42	1.16964	1.026
1000	3	3.14	9.8596	9.42
1000	3	3.2	10.24	9.6
10000	16.7	1.78	31.684	29.726
100000	29.9	0.42	17.64	12.558
1000000	33	0.12	14.4	3.96

Run 2

Time (min)	Resistance (Kohm)	Top Temp (C)	Bot Temp (C)	Avg. Temp (C)
0	20.4	22.8	16.3	19.55
1	20.4	24.9	16.1	20.5
2	21	29.1	16.2	22.65
3	21.5	35.3	16.1	25.7

delta Temp = 19.8 C (uncorrected)=11.6 C (corrected)
Top Temp = 36.8 C, Bot Temp = 17.0 C

Resistance (ohms)	Voltage (mv)	Current (uA)	Power to Load (I^2*R)(nanowatts)	Power (VI) (nanowatts)
1	0	2.48	0.0061504	0
10	0	2.45	0.060025	0
100	0.2	2.43	0.59049	0.486
1000	2.1	2.18	4.7524	4.578
1000	2	2.14	4.5796	4.28
10000	10.9	1.18	13.924	12.862
100000	19.5	0.3	9	5.85
1000000	21	0.13	16.9	2.73

Run 3

Time (min)	Resistance (Kohm)	Top Temp (C)	Bot Temp (C)	Avg. Temp (C)
0	20.3	22.2	16.3	19.25

delta Temp = 6.6 C (uncorrected) = 3.1 C (corrected)
Top Temp = 22.9 C, Bot Temp = 16.3 C

Resistance (ohms)	Voltage (mv)	Current (uA)	Power to Load (I^2*R)(nanowatts)	Power (VI) (nanowatts)
1	0	0.79	0.0006241	0

1	20.3	22.6	16.1	19.35

10	0	0.78	0.006084	0
100	0	0.77	0.05929	0
1000	0.6	0.71	0.5041	0.426
1000	0.6	0.68	0.4624	0.408
10000	3.1	0.44	1.936	1.364
100000	5.7	0.19	3.61	1.083
1000000	6.3	0.1	10	0.63

Run 4

Time (min)	Resistance (Kohm)	Top Temp (C)	Bot Temp (C)	Avg. Temp (C)
0	20.4	20.6	15.5	18.05
1	20.4	22.4	15.6	19
2	20.9	26.1	16	21.05
3	21.36	32.4	15.8	24.1
4	21.7	35	16.2	25.6
5	22	39.5	16.2	27.85
6	22.2	40.7	16.7	28.7
7	22.3	42.3	16.6	29.45
8	22.4	43	16.9	29.95
9	22.5	43.9	17	30.45
10	22.1	40.3	17.1	28.7
11	21.5	32.5	17	24.75
12	21.1	29.7	17	23.35
13	20.9	28.6	16.7	22.65
14	20.7	25.6	16.6	21.1
15	20.6	24.1	16.5	20.3
16	20.5	23.6	16.5	20.05

delta Temp = 35.8 C (uncorrected) = 21.9 C (corrected)
Top Temp = 53.8 C, Bot Temp = 18.0 C

Resistance (ohms)	Voltage (mv)	Current (uA)	Power to Load (I^2*R)(nanowatts)	Power (VI) (nanowatts)
1	0	4.41	0.0194481	0
10	0	4.38	0.191844	0
100	0.4	4.32	1.86624	1.728
1000	3.8	3.92	15.3664	14.896
1000	3.7	3.85	14.8225	14.245
10000	19.8	2.11	44.521	41.778
100000	35.4	0.5	25	17.7
1000000	38.8	0.13	16.9	5.044

Temp	Peak Load	Cur. (amps)	Volt. (mv)	Coef(uV/C)
3.1	1.936	0.00000044	4.4	118.2796
11.6	13.9	1.179E-06	11.78983	84.69703
18	31.7	1.7804E-06	17.80449	82.42821
21.9	44.521	0.00000211	21.1	80.28919